The Terrain-Induced Rotor Experiment (T-REX)

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Introduction: The Terrain-induced Rotor Experiment (T-REX) is a coordinated international effort focused on exploring the structure and evolution of atmospheric rotors and associated phenomena in complex terrain.[1] Atmospheric rotors are intense low-level horizontal vortices that form along an axis parallel to and downstream of a mountain ridge crest in association with large-amplitude mountain waves. High levels of turbulence characterize rotors, which are known to pose a great hazard to aviation. Recent numerical, theoretical, and observational studies of rotors[2,3] show that rotors are strongly coupled to both the structure and evolution of overlying mountain waves and to the underlying boundary layer. Consequently, the overarching objective of T-REX is to study synergistic interaction between rotors, mountain waves, and boundary layer dynamics. The T-REX field campaign was centered on the Owens Valley in the lee of the southern Sierra Nevada in eastern California. This portion of the Sierra Nevada is the tallest, quasi-two-dimensional topographic barrier in the contiguous United States; it includes the highest peak in the lower 48 states (Mt. Whitney 4,418 m) and the steepest lee slopes.

Experimental Design: The T-REX experimental design reflects the need to document a coupled system of deep vertical extent, reaching from the ground to upper tropospheric–lower stratospheric altitudes. The major portion of the ground-based instrumentation was deployed within the focus region in the Owens Valley. Four major groups of instruments were present during T-REX: (i) the surface station network, (ii) ground-based remote sensors, (iii) flux measuring instruments, and (iv) radiosondes. The ground-based instrumentation included scanning and dual-Doppler lidars and three radar profiler systems (Fig. 1(a)).

In order to document the mesoscale structure and evolution of the wave/rotor part of the coupled system over Owens Valley, and the kinematic and thermodynamic structure of airflow through the depth of the troposphere upstream and downstream of the Sierra Nevada, three research aircraft were involved in the T-REX campaign: the National Science Foundation (NSF)/National Center for Atmospheric Research (NCAR) High-performance Instrumented Airborne Platform for Environmental Research (HIAPER); the UK Facility for Airborne Atmospheric Measurements (FAAM) BAe146; and the University of Wyoming King Air (Fig. 1(b)). The three aircraft covered the range of altitudes from nearly 150 m above ground within the Owens Valley to about 14 km in the lower stratosphere. In addition to the probes for in situ kinematic and thermodynamic measurements, the special instrumentation carried by the aircraft included (i) a cloud radar (King Air), (ii) in situ chemical tracer instruments and microphysics probes (HIAPER and BAe146), and (iii) dropsonde systems (HIAPER and BAe146) (Fig. 1(b)).

Real-Time Numerical Model Forecasts: The T-REX field operations were supported by a real-time forecasting effort that included a number of mesoscale, medium-range global, and mountain wave prediction models. The special real-time models and output provided in support of T-REX were augmented by the widely available forecast models from U.S. and international operational centers. High-resolution mesoscale forecast models were executed by various groups to specifically support the T-REX forecasting operations. The NRL Marine Meteorology Division provided high-resolution forecasts (horizontal grid increment of 2 km) for T-REX using the atmospheric module of the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS®).* The NRL COAMPS effort was the backbone of the T-REX high-resolution mesoscale real-time forecasting capability. The initial conditions for COAMPS were obtained through mesoscale data assimilation, which were used for twice-daily 48-h forecasts, with lateral boundary conditions from the Navy Operational Global Atmospheric Prediction System (NOGAPS). Other supporting mesoscale model efforts included the WRF-NMM, WRF-ARW, and MM5 forecasts performed by NOAA/NCAR, the Army Research Laboratory (ARL), the National Weather Service (NWS), and the Air Force Weather Agency (AFWA). Because of timeliness and availability issues, the T-REX forecasters primarily relied on the 2-km resolution COAMPS, a 4-km resolution WRF-NMM, and the 12-km National Centers for Environmental Prediction (NCEP) Eta for mesoscale model guidance. Real-time forecasts from linear theory models produced by NRL-Monterey and the UK Met Office augmented the short guidance for T-REX mission planning.

A comparison of the real-time COAMPS forecast vertical velocity with the HIAPER observations at 13.1 km (above sea level) is shown in Fig. 2 for six of the T-REX Intensive Observation Periods (IOPs). The IOPs 4, 6, and 13b were considered among the strongest during the field campaign, while IOPs 9, 10, and 13a were the weaker events. The HIAPER flew a series of cross-mountain-oriented race track patterns above the Sierra in the upper troposphere and lower stratosphere. The results are stratified into northern and southern

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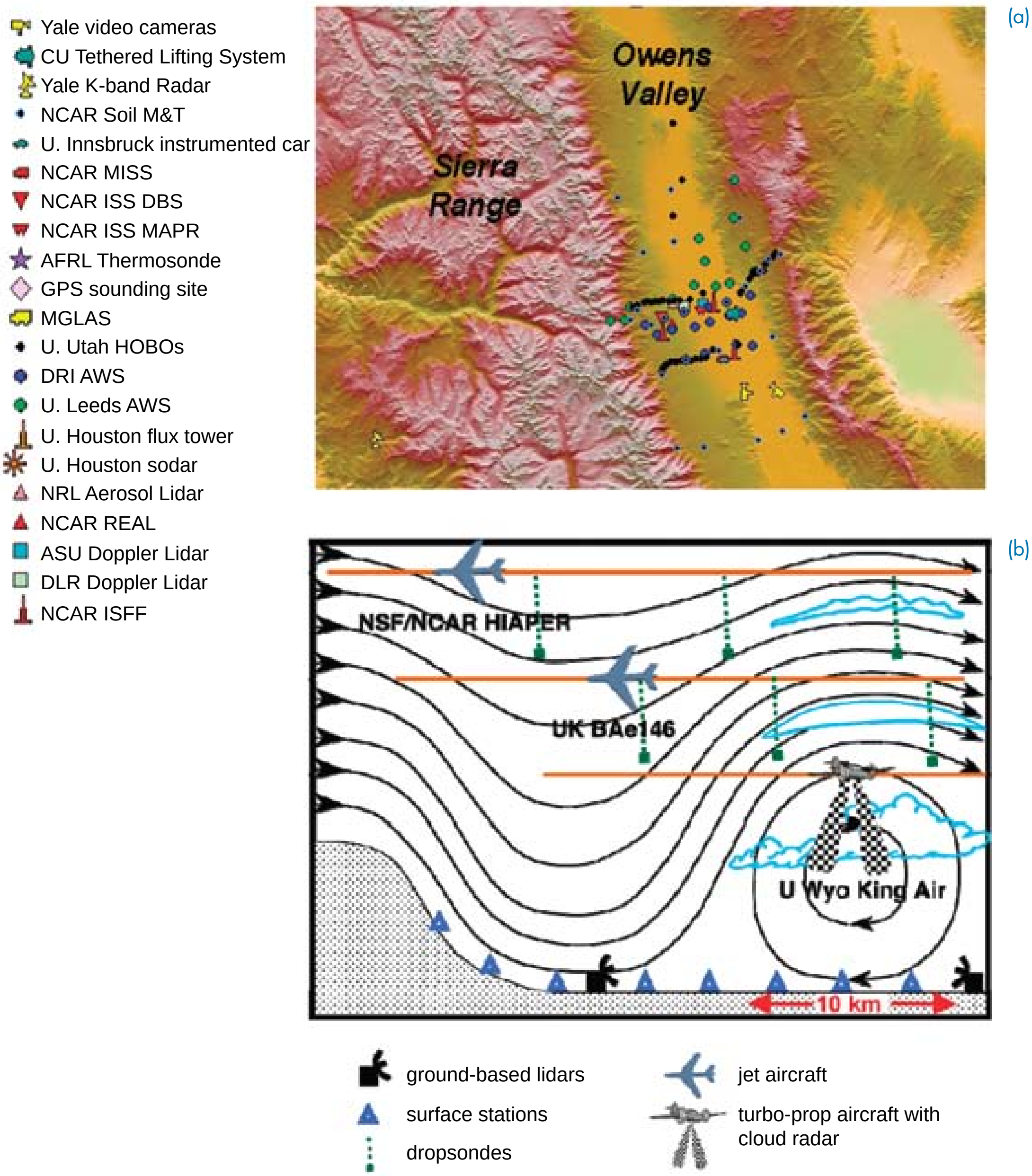

FIGURE 1
(a) Color relief map of the southern Sierra Nevada showing the T-REX field campaign ground-based instrumentation network. (b) A schematic view of the composite T-REX airborne observing network comprising three aircraft along with other major instrumentation in approximate relation to rotor type of phenomena.

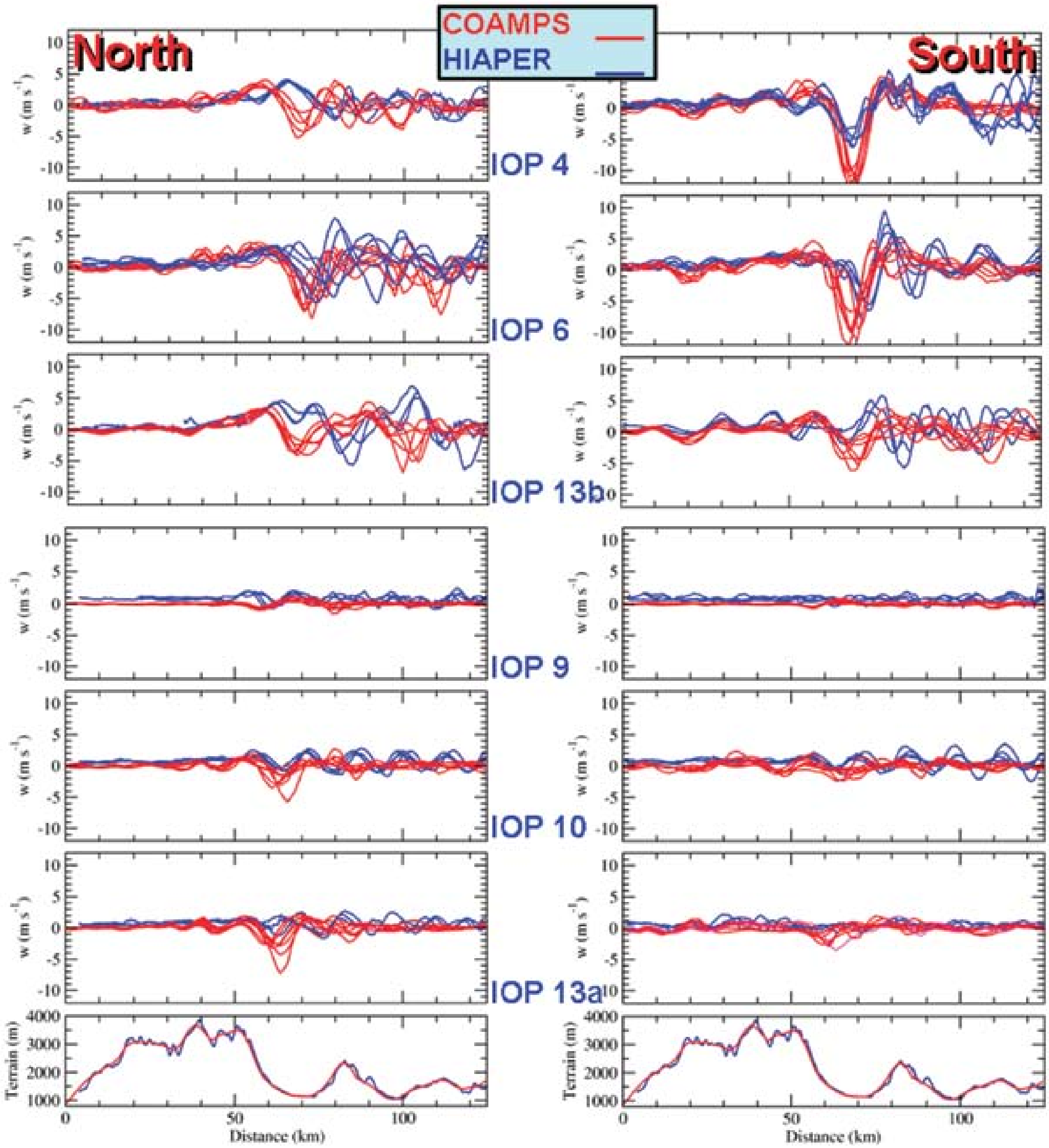

FIGURE 2
Vertical velocity (m s^{-1}) derived from the real-time COAMPS forecasts (red) and HIAPER observations (blue) at 13.1 km ASL. The data are stratified for the northern and southern cross-mountain flight segments. Terrain (m) is interpolated to the aircraft transect derived from a digital elevation model (blue) and from the COAMPS model terrain (red).

segments in Fig. 2. The real-time forecasts were able to consistently distinguish the strong and weak events and were generally able to characterize the gravity wave amplitudes and wavelength differences between the north and south segments.

Summary: Spring 2006 was a very active period of mountain waves over the Sierra Nevada. A large number of mid-latitude weather systems, greater than the climatological average, passed over the T-REX target area, yielding many opportunities for special observations of the coupled rotor system. This was also a very moist period in the Sierra Nevada, bringing the effect of moisture on mountain waves and rotors more strongly into focus. Fifteen IOPs were conducted during the two-month field campaign including 12 HIAPER, 25 King Air, and 11 BAe146 research flights. More than 350 dropsondes were deployed along with more than 400 radiosondes. Preliminary results indicate that the T-REX observations reveal new insights into the interactions of internal waves, rotors, and boundary layer properties over complex topography. The emergence of a new generation of observing platforms and high-resolution numerical models such as

COAMPS represents an unprecedented opportunity for fundamental studies of gravity waves and rotors.

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